

Late Llandovery and early Wenlock stratigraphy and ecology in the Oslo Region, Norway

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SYNOPSIS. New fossil collections and field work in all parts of the Oslo Region in rocks of middle and late Llandovery and early Wenlock ages have led to a reassessment of the stratigraphical units, including the erection of a new Porsgrunn Formation of late Llandovery age in the Skien, Porsgrunn and Holmestrand districts. The fossils used for dating are reviewed in turn, with new graptolite records and new finds recorded of the age-diagnostic brachiopod *Eocoelia sulcata*. Many faunal assemblages and animal communities have been recognised, most of which are known from Britain, Canada and elsewhere. The new strophomenacean brachiopod genus *Erinostrophia* is erected, with type species *Orthis undata* M'Coy, 1846. Analysis of the deepening and shallowing of the animal communities, combined with a review of the sequence stratigraphy, leads to a recognition that, in addition to the variable influences of global eustatic changes, the more local isostatic responses to contemporary nappe emplacement were more important in controlling the depths and facies.

INTRODUCTION

The Silurian rocks of the Oslo Region are a challenge to biostratigraphers: they appear at first sight to be well exposed and very fossiliferous, but on closer inspection the exposure is discontinuous and the critical fossils for dating are often hard to find in many parts of the region. The rocks crop out sporadically over a large area over 220 km long from north to south and up to 80 km wide (Fig. 1), but in many places they have been metamorphosed by Permian intrusions; they are often intensely folded and faults are common. Even though they are in places exposed in sea or lake coastal sections it is often difficult to define lithostratigraphical boundaries and to measure complete sections with accuracy. Apart from crinoids and tabulate corals, which have not so far proved useful for dating, the fossils are often sparse or badly affected by cleavage or metamorphism, although they may sometimes be found excellently preserved, especially after careful preparation. The rocks of middle and later Llandovery and early Wenlock age form an important amount of the total Lower Palaeozoic sequence of the Oslo area and are the subject of this paper. To date this sequence it has been necessary to use a wide variety of fossils: graptolites, brachiopods, acritarchs, conodonts and even the button coral *Palaeocyclus*. In many cases these ages are not as precise as we would wish owing to the sporadic distribution of the fossils. We have also tried to evaluate the shifting patterns of the faunal distribution of macrofossils and to integrate these with the lithologies in order to understand something of the local environment and palaeobathymetry, which of course varied immensely in both time and space through such a substantial area.

The Oslo Region can be compared with coeval areas elsewhere, particularly the Welsh Borderland (Ziegler *et al.*

1968a), and one object of our studies has been to evaluate probable sea level changes and to compare them with areas in other palaeocontinents (McKerrow 1979, Johnson *et al.* 1981, 1991), following preliminary work by Johnson & Worsley (1982).

The most substantial previous study of these rocks remains that by Kiaer (1908), who summarised earlier nineteenth century work by Brøgger, Kjerulf and others including Murchison. Kiaer divided the rocks by a number and letter system into 'Etagen' or 'Stages' from the Cambrian to the late Silurian, and most of the present paper deals with his stages 7 and 8. Worsley *et al.* (1983) have provided a modern stratigraphical framework of formation names for the region and demonstrated some diachroneity in a few of Kiaer's subdivisions, the various authors in Worsley (1982) have published many new fossil identifications, and Baarli (1990) has published some useful ecological data on the Vik Formation in Malmøya (Oslo) and Sandvika (Asker). However, Kiaer remains the basic reference for many detailed sections over the area as a whole. The present paper concentrates on the later Llandovery of the area following work on the middle Llandovery (chiefly the Rytteråker Formation) by Möller (1987, 1989).

The various dating criteria will be reviewed first, followed by brief descriptions of the faunal assemblages which we have found, the details of the various formations and a geological history of the area.

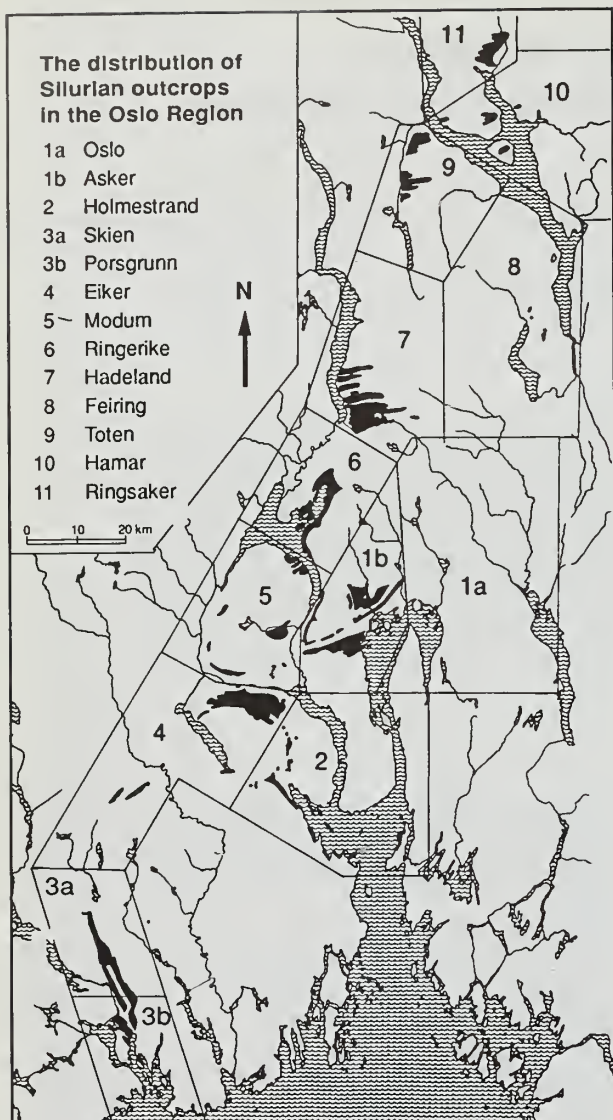


Fig. 1 Outcrop map of the Silurian of the Oslo Region, showing the districts mentioned in the text.

SHELLY CORRELATION ELEMENTS

Stricklandia–*Costistricklandia*

Since Williams (1951), this brachiopod lineage has afforded one of the best means of dating shelly rocks of Lower Silurian age. The earlier parts of the lineage are particularly well documented in the Oslo Region (Baarli 1986) and the later parts, those with *Stricklandia laevis* and *Costistricklandia lirata*, are also now known (Baarli & Johnson 1982, 1988). *S. laevis* has previously been recorded from the lower part of the Vik Formation in Asker, Malmøya and Modum and *C. lirata* from the upper Vik in Asker and the middle Vik and upper Bruflat in the Ringerike district. Baarli & Johnson (1988) also recorded and figured *Costistricklandia lirata* from the lower Vik Formation in the Skien district. However, the abundant stricklandiids which we have collected in the lower and

middle Vik Formation in the Skien, Porsgrunn and Holmestrand districts (Fig. 7g–i) are identified here as *Stricklandia laevis* rather than *Costistricklandia lirata* since there are no substantial ribs and the cardinalia are also typical of that species. This change of identification from that of Baarli & Johnson makes a significant impact on the age deduced for the lower and middle Vik Formation of the southern parts of the Oslo region. We have also found *S. lens progressa* from the lower part of the Vik Formation in Asker. All these records have been instrumental in forming some of the most useful parameters for our correlation diagram of the area (Fig. 3).

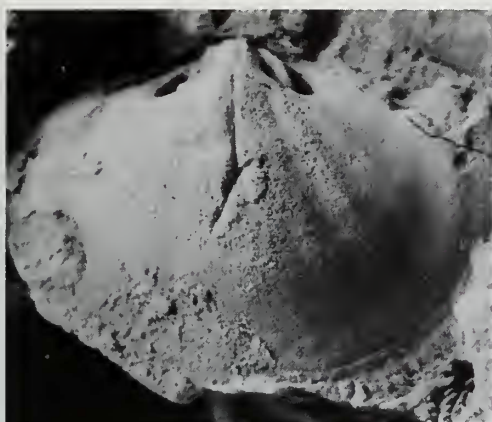
Pentamerus–*Pentameroides*

Baarli & Johnson (1982, p. 96) have documented the transition between *Pentamerus oblongus* and *Pentameroides* cf. *subrectus* in beds 12 m above the base of the middle Garntangen member of the Vik Formation at Purkøya, Ringerike district and Baarli & Johnson (1988) added new records from Baerum. We have found *Pentameroides* to be abundant as low as 10 m above the base of the Vik Formation at Skien (Fig. 7j) and Porsgrunn and perhaps 20 m above the base at Holmestrand. These records are rather lower in the formation than expected, and probably indicate diachroneity of the lithologies.

Eocoelia

Since the classic work on the evolution of *Eocoelia* in the Llandovery by Ziegler (1966), the genus has been documented as also occurring in early Wenlock rocks by Bassett & Cocks (1974) as the species *E. angelini* (Lindstrøm). Although Kiaer (1908) described the lower part of the Llandovery sequence in Oslo as '6a, the zone with *Leptocoelia hemisphaerica*, Sow.', that common brachiopod has been shown (Thomsen & Baarli 1982, p. 64) to be a misidentification of the basal Silurian *Zygospiraella duboisi* (Verneuil). True *Eocoelia* has only been documented from the Oslo region below the Wenlock in a single record of *Eocoelia hemisphaerica* (Figs 7a–c) from the Rytteråker Formation of the Skien area (Baarli & Johnson 1988). Within rocks of Wenlock age, *Eocoelia angelini* has been found in the Braksøya Formation at Ringerike by Ziegler (1966 p. 538 — identified there as *E. sulcata*, but correctly re-identified by Bassett & Rickards 1971).

We have also found true *Eocoelia sulcata*, another new record for the Oslo Region (Fig. 7d), in the Porsgrunn Formation, 34 m below the contact with the overlying Braksøya Formation, at Kommersøya, Holmestrand district (Grid Ref. NL 750991), where it occurs with *crenulata* Zone graptolites. At the top of our sequence, the species *E. angelini* has been recorded from the Braksøya Formation at its type locality in the Ringerike district (Worsley *et al.* 1983, p. 35). These workers regard it as suggesting a mid-Sheinwoodian (*riccartonensis* Zone) age for that formation based on the co-occurrence with *riccartonensis* Zone graptolites in Gotland (Bassett & Cocks 1974). We have also found *E. sulcata* within 2 m of the base of the Malmøya Formation in the Baerum district at Daeliveien, (Locality 30, Grid Ref. NM 859428) and at Asterudveien (NM 869442). Locality 30 is in the same section and stratigraphically above Locality 27, which is Skinnerbukta Formation yielding *centrifugus* Zone age graptolites. This is a most important find, since it is the first certain



a



b

Fig. 2 *Eocoelia sulcata* (Prouty, 1923), from early Wenlock Malmøya Formation, Locality 30; 2a, internal mould of a pedicle valve, BC 10570, x 10; 2b, latex cast of the external mould of a pedicle valve, showing faint ribbing and frilly ornament, BC 10568, x 9.

record of *Eocoelia sulcata* (Fig. 2) from the Wenlock anywhere. Hitherto it has been assumed that *E. sulcata* evolved into *E. angelini* at about the Llandovery–Wenlock boundary, but now it seems clear that evolution took place within the *murchisoni* Zone.

Erinostrophia undata

In Appendix 1 below we erect the new generic name *Erinostrophia* for the large rugose brachiopod which has been known in the stratigraphical literature as *Strophomena walmstedti*, or *Megastrophia* (*Protomegastrophia*) *undata* or by almost any combination of these names. It is known from Gotland, Scotland and Ireland (Fig. 8a) as well as from Norway (Figs 8b–f), and it appears to be both a distinctive and easily recognizable form and also stratigraphically restricted to a narrow interval at the very top of the Telychian. There is no certain proof that it ever extended up into the Wenlock and it thus can be used as a sensitive age indicator for rocks corresponding to the *crenulata* Zone.

Palaeocyclus

The small button coral *Palaeocyclus porpita* is well known from many late Llandovery localities, for example in Gotland, Wales, Scotland, Ireland and Canada (Gaspé), and it can often occur in very large numbers. In the Oslo Region, we have found it in the upper part of the Porsgrunn Formation, e.g. near Gjerpen Church, Skien (Grid Ref. NL 347654) and in the type section (Fig. 4) and in the lower part of the Braksøya Formation at Skien, Porsgrunn and Holmestrand. It is also common in parts of the Bruflat Formation in Ringerike and further north, for example in the railway section north of Jevnaker, Hadeland (NM 787825), although we have not found it in the Bruflat Formation of Toten. Although *Palaeocyclus porpita* is undoubtedly most abundant in rocks of *crenulata* Zone age, both in the Oslo Region and elsewhere, it is as yet unresolved whether or not this coral lingered on into earliest Wenlock time, but there is no hard evidence that it did. In the well-studied Vattenfallet section of Gotland, it is apparently confined to the Lower Visby Marl of late Llandovery age (Neuman & Hanken 1979) although there are other unconfirmed records of *Palaeocyclus* in the earliest Wenlock Upper Visby Marl.

OTHER CORRELATION ELEMENTS

Graptolites

Graptolites are relatively scarce in the Oslo Region, apart from the common assemblages in the Ek Formation of Toten and Ringsaker and the basal Skinnerbukta beds at Malmøya (Howe 1982), although there are a few other records of occasional specimens in Kiaer (1908) and Bassett & Rickards (1971). We have collected graptolites from several new localities which have proved crucial to our correlation, particularly of the Porsgrunn and Skinnerbukta formations. These have been identified for us by Dr R.B. Rickards, and consist of the following:—

Porsgrunn Formation: Locality 2 — *Monograptus priodon*? *M. parapriodon* — indicating *crenulata* Zone age. Locality 3 — *Monoclimacis* (long); cyrtograptid arm.

Bruflat Formation: Locality 14 — *Monograptus sensu stricto* — uncertain age.

Skinnerbukta Formation: Locality 26 — *Monoclimacis vomerina vomerina*; *M. v. aff. basilica*, *Monograptus cf. priodon* — together indicating *centrifugus* or low *murchisoni* Zone age. Locality 27 — *Retiolites geinitzianus angustifrons*; *Pristiograptus cf. watneyae* — probably indicating *centrifugus* Zone age. Locality 33 — *Monograptus priodon*; *Monoclimacis vomerina basilica* — indicating *centrifugus* or low *murchisoni* Zone age.

Microfossils

New studies on conodonts from the Vik Formation at Malmøya, Oslo, and at Sandvika, Baerum, and the Rytteråker Formation at Malmøykalven, Oslo, have been made by Nakrem (1986). Aldridge & Mohamed (1982) have also figured some conodonts from the Bruflat Formation of Ringerike, the Vik Formation of Holmestrand and Asker and from what we would now term the Porsgrunn Formation of Skien. These studies have recognised *celloni* Zone faunas



Fig. 4 Upper part of Porsgrunn Formation at Øyekastvegen, Porsgrunn (NL 370555), showing interbedded bioclastic siltstones and limestones with cross sections through the button coral *Palaeocyclus porpita* (diameter of each coral is approximately 1 cm).

from the lower part of the Vik Formation and *amorphognathoides* Zone faunas from the upper Vik, lower Skinnerbukta and middle Bruflat Formations. Palynomorphs have been studied in the Ringerike District by Smelror (1987) who has recognised the zones erected by Hill (1974; revised Hill & Dörning in Cocks et al. 1984) in the Welsh Borderland and the type Llandovery area in Wales. Smelror recognised the Zone 3 — Zone 4 boundary two-thirds way up the Vik Formation at Ringerike and the Zone 4 — Zone 5 boundary near the top of the Bruflat Formation. Although most of these micropalaeontological data are less precise than those from the graptolites and shelly fauna, they are useful confirmatory evidence in correlation.

FAUNAL ASSEMBLAGES

Although Kiaer (1908) listed a great many species from late Llandovery and early Wenlock beds from many localities in the Oslo Region, closer inspection of these lists shows that very few of the species names are known from coeval beds elsewhere. Most of the names are generalised from, for example, Davidson's brachiopod monograph from the Wenlock of Britain (Davidson 1866–71). In fact, there has been little systematic palaeontological work done on the late Llandovery or early Wenlock brachiopods of the Oslo Region, apart from that on the strophomenids by Holtedahl (1916), a few illustrations in a preliminary survey by Cocks & Baarli (1982) and a description of the enteleteaceans by Baarli

(1988). Monographic revisions of the fauna would be desirable, although the potential task of assembling truly adequate collections is daunting. However, we have collected systematically from 35 localities (Tables 1,2) yielding over 5000 specimens in the Palaeontologisk Museum, Oslo (PMO) and The Natural History Museum, London (BB,BC). In addition, we have observed many comparable fossil assemblages in the field without making detailed collections, and Baarli (1990) has identified 302 fossils from 7 collections in the Vik Formation of Malmøya, Oslo, and 567 specimens from 5 collections in a section in the Vik Formation at Kampebråten, Sandvika (area 1b on our Fig 1).

Many of the assemblages present may be assigned to those previously recognized from the late Llandovery of the Welsh Borderland (Ziegler *et al.* 1968a, Cocks & McKerrow 1984) and elsewhere, namely the *Eocoelia*, *Pentamerus/Pentameroides*, *Stricklandia* and *Clorinda* Communities (Fig. 6). However, in the Oslo Region these assemblages are supplemented by bioherms, shallow-water molluscan dominated assemblages and two other assemblages, the *Atrypa-Hallopora* Community of the mid-shelf and the *Eoplectodonta-Atrypa* Community of the deeper shelf, upon which brief notes follow. As with the Welsh Borderland (Ziegler *et al.* 1968b) the presence of these assemblages has assisted in the recognition of deepening and shallowing trends in the various formations, which are reviewed later.

Table 1 Fossils recovered from various localities in the Vik Formation. The localities are given in Appendix 2.

Locality Number	17	23	24	25	5	21	34	19	29
Craniops									2
Orbiculoidea									1
Dictyonella	3						1		
Hesperorthis									
Skenidioides	8	4			3				15
Indet. orthid	1								
Isorthis	2	16		2		1			19
Dalejina								1	
Resserella								1	1
Visbyella				1					
Dicoelosia								2	47
Eoplectodonta	1							5	21
Aegiria					11				
Katastrophomena									1
Leptostrophia			1						
Brachypirion	13	4							
Mesopholidostrophia				1	1				
Protochonetes	3								
Pentameroides	99	79	96	45					
Stricklandia	3	3	1	32	38	23	16		
Clorinda	59	31	7	16	2	5			
Parastrophinella	1								
Atrypa	13	23	4	145	178			9	14
Atrypina									1
Hyattidina		1							
Glassia	2	6							
Pentlandella	17								
Eospirifer					14			4	
Cyrtia									15
Tabulate corals	24	48	9	7	21	1			
Rugose corals	23	16		2	4			2	3
Bryozoa	10	12	4		28	1	7	23	34
Molluscs		1			2			3	6
Ostracods								3	
Trilobites				1	1	1		2	10
Crinoids	2	7	3		2		1	32	115
Others	2	3		11	6			2	2
Total	285	254	125	263	309	32	25	90	307
Total species	26	21	11	15	17	6	5	18	28

Shallow-water

Bioherms

These are best developed in the early Wenlock Braksøya Formation, and extend from Porsgrunn northwards as far as Ringerike. They have not been collected and examined closely in the present study but are briefly described in Worsley *et al.* 1983, pp. 33–36.

Mollusc dominated assemblages

At the top of the Bruflat Formation, for example in the railway cutting south of Reinsvoll (Grid Ref. NN 881269), some bedding planes are covered with a variety of molluscs, dominantly gastropods. Our collection (Locality 13) has had the following molluscs identified by Dr N.J. Morris: Gastropods:—*Oriostoma* cf. *acuta* Lindström (80 specimens and 20 operculae), *Loxonema* sp. (46), *Gyronema*? sp. (42), *Raphistomina* sp. (19), and *Crespedostomus* sp. (1). Bivalves:—*Pteronitella* sp. (19), *Praenucula* sp. (7), *Koenenia*? sp. (1), ?grammysiid (1) and cyrtodontid (1); as well as a michelinoceratid cephalopod (6). The rest of the collection consisted of

the brachiopods *Erinostrophia undata* (6 pedicle valves, 3 brachial valves), *Isorthis* sp. (4,3) and a single pedicle valve each of *Pentlandina* sp., *Atrypa* sp. and *Atrypina*? sp., 8 bryozoans, the trilobites *Dalmanites* (1), a calymenid (4), and a lichid (1); *Cornulites* (1), *Tentaculites* (5) and a few disarticulated crinoid columnals, making a total of 223 molluscs out of a collection of 269 specimens, or 83%. These occurrences, although not identical to any found in the Welsh Borderland, are comparable to the assemblages found in beds of approximately the same age in south-east Dyfed (Pembrokeshire), Wales (Walmsley & Bassett 1976).

Eocoelia Community

An interbed of shale within the limestones of the Rytteråker Formation at a road cut in Skien (Locality 11, Grid Ref. NL 336657) yielded a small fauna consisting of *Protatrypa* (18 pedicle valves, 9 brachial valves), *Eocoelia hemisphaerica* (J. de C. Sowerby) (4,11), *Pentamerus* (4,5), *Stricklandia* (1p.v.), *Clorinda* (1p.v.), and 9 pieces of crinoid columnals. The *Eocoelia hemisphaerica* is of particular interest (Fig. 7a–c), since it is the first record of the species from the Oslo Region (Baarli & Johnson 1988). Although specimens of

Table 2 Fossils recovered from various localities in the Porsgrunn (P), Skinnerbukta (S) and Bruflat (B) Formations. The localities are given in Appendix 2.

Locality Number	P 36	P 22	P 20	P 8	P 1	P 4	P 18	P 6	P 2	P 3	P 9	P 10	S 31	S 35	B 14	B 16	B 39
Craniops	2		1	3				1		2	1	2					1
Dinobolus		1															
Petrocrania													1				
Orbiculoidea		2							1								
Philhedra			1														0
Skenidioides	9	4	3	3				1	1								
Indet. orthid									1	1							
Isorthis	9	40	13	3		2	2	51			10		3	63	3	14	5
Salopina							2										
Dalejina	5				1				5	5		1					
Resserella			1	5					4	6							3
Dicoelosia	7	14	9	2						20							
Triplexia												1				1	
Leangella									1								
Eoplectodonta	21	33	27	18	1	1			1	8	9	5	1				19
Jonesea		1															
Leptaena	3	7		1	1			1	4	6			5			5	7
Pentlandina			3														
Cyphomenoidea								1				1					1
Katastrophomena	4								1	7							1
Leptostrophia										2							
Strophonella			1														
Protomegastrophia				1	1				2	2							
Erinostrophia				12			2								73	10	
Amphistrophia		1		1							1						
Mesopholidostrophia					1		3					1					
Coolinia	10	1	2		1		1			2			2				3
Protochonetes	4			4		2	40	1		3	1		1	2		16	
Clorinda		2															
Eocoelia										3				81			
Rostricellula							1										
Sphaerirhynchia				2		3	4				8					4	
Rhynchonellid										1					1	1	
Atrypa	11	30	38	27			3	7	73	14	35	9	6		68	14	22
Atrypina		10					2									5	
Hyattidina						7	115									23	
Glassia		2	2	3							1	1					1
Homoeospira				10							1		1				
Eospirifer	3		1						2		1						
Cyrtia	17	7	10	2	1					1	6	1					4
Howellella									3	3	1						
Indet. brachiopods								1									
Tabulate corals	5			5			6		2		1				3	10	
Rugose corals	7	16				17	6		3		2	2			5	12	1
Bryozoa	53	10	17	12	6	13	56	23	34	141	18	10	18	67	80	113	6
Molluscs	1	6	24	2		6	4	1	3	8	5	2		1	4	58	2
Ostracods		3	24	62		4		5		11	7	9	1	19		8	
Trilobites	14	16	12	6	2	1	3	7	6	6	2	8	4	2	2	2	5
Crinoids	9	12	20	14		17	40	7	4	4	17	7	1	2	7	134	
Others	14	1	8	5	3	3	5	5	3	10	2		2	24	3	3	
Total	209	219	221	189	19	88	295	112	153	268	123	69	46	261	239	423	81
Total species	27	28	30	27	14	17	25	21	26	31	26	21	15	9	18	30	17

Eocoelia sulcata have been found in the Porsgrunn Formation (Fig. 7d), another new record, the assemblage in which they occur (Locality 3), is dominated by *Atrypa* and *Resserella* (Table 1) and represents a mid to deeper shelf community. The next *Eocoelia* community assemblage is to be found near the base of the Malmøya Formation (Fig. 2), for example at a roadside exposure at Daeliveien, Baerum, (Locality 30: Grid Ref. NM 859428) which yielded *Eocoelia sulcata* (124 pedicle valves, 94 brachial valves), *Isorthis?* sp. (44,29), *Protocho-*

netes (24,9), *Coolinia* (3,7), *Stegerhynchus* (4,5), *Cryptothyrella* (4,3), and single valves of *Eoplectodonta*, *Erinostrophia undata* and *Atrypa*, as well as 53 bryozoans, a gastropod, *Pteronitella* (3), *Harpidella* (3), *Tentaculites* (27), 12 ostracods and a single crinoid ossicle.

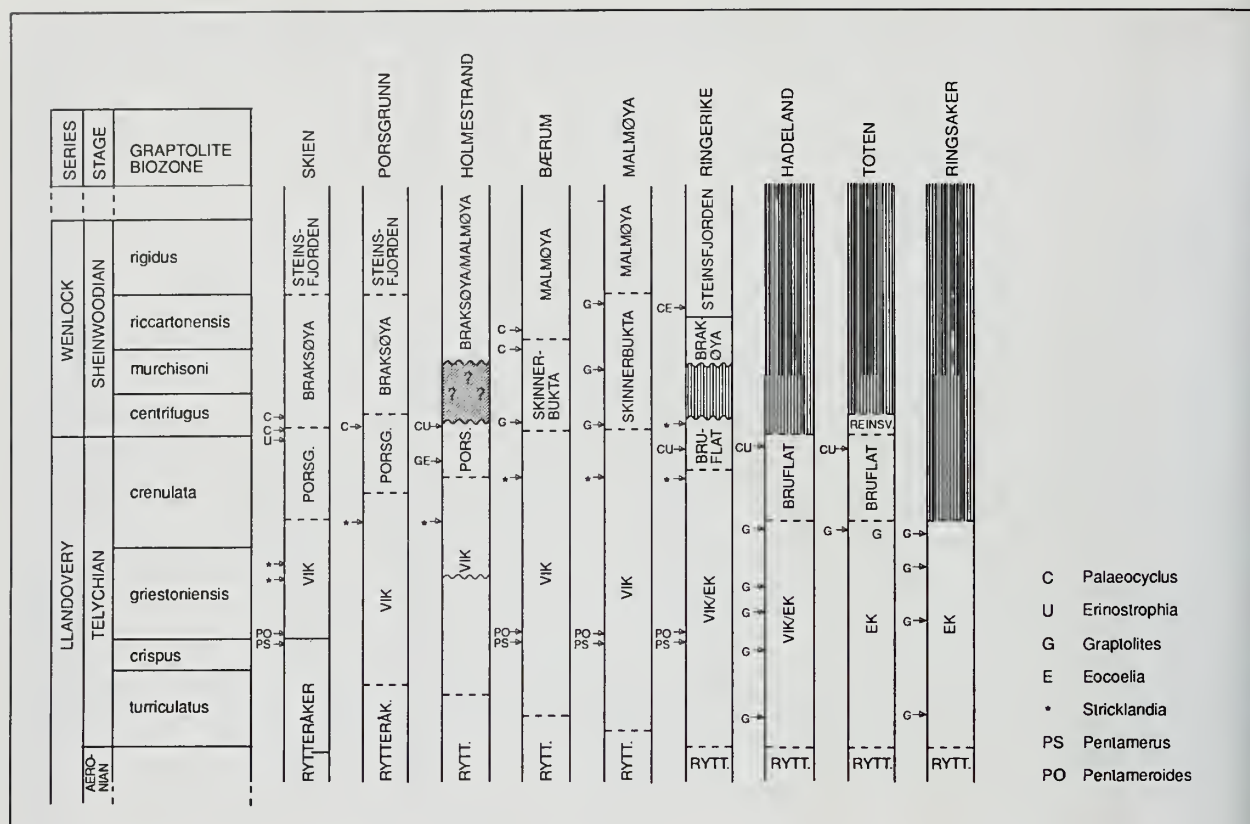


Fig. 5 Composite sections through selected late Llandovery and early Wenlock rocks of the Oslo Region. The vertical scale shows time.

Mid-shelf

Atrypa-Hallopora Community

This community recurs in the Vik, Porsgrunn and Bruflat formations, and is dominated by the brachiopod *Atrypa* and the bryozoan *Hallopora*. Good collections have been obtained from the Porsgrunn Formation at Holmestrand (Localities 2,3) and at Skien (Localities 9,10) where between 21 and 31 different species have been recorded (Table 2), including in Locality 3, *Eocoelia sulcata* (Fig. 7d). Both the faunal diversity and the general lithostratigraphical situations suggest that this fauna lived in the mid-shelf; although in the Bruflat Formation in Hadeland the main elements of the community are joined by dominant *Erinostrophia* (Locality 14) and other elements which are known from shallower water such as *Protochonetes* and *Hyattidina* (Locality 16), all suggesting the shallower part of the middle shelf.

Stricklandia and *Pentameroides* Communities

These assemblages are well known from many parts of the world, following their original description from the Welsh Borderland (Ziegler *et al.* 1968a), and are common in the Oslo Region. In particular we have many new records from the Vik Formation (Table 1) of the southern part of the region (Fig. 7j), particularly in the Skien (Localities 5,23–25) and Porsgrunn (Localities 17,21) districts, and a representative sample from Ringerike (Fig. 7i, Locality 34) from which these communities are already recorded (Baarli & Johnson

1988). Baarli (1990) has also recorded them from the Vik Formation of Sandvika and Malmøya.

Deeper-shelf

Eoplectodonta-Atrypa Community

This community has a comparable ecological position to the *Clorinda* Community (see below), however, *Clorinda* itself is absent (apart from 2 specimens from Locality 22). It is known from the Porsgrunn Formation at Holmestrand (Locality 1), Skien (Locality 8) and Porsgrunn (Localities 20,22) and from the Vik Formation at Skien (Locality 19) and Malmøya (Locality 29). Its diversity is fairly high, and it includes such forms as *Dicoelosia* and rare *Jonezea* (a common plectambonitacean formerly recorded from many places under the name of *Aegiria grayi*) which are only known elsewhere from outer shelf deeper-water deposits.

Clorinda Community

At only one place (Locality 32), in the Vik Formation at Bærum, have we collected a sparse but typical *Clorinda* Community consisting of 7 specimens of *Clorinda globosa*, one each of *Eoplectodonta penkillensis* and *Atrypa* and a mere two small ostracods. Elsewhere in the late Llandovery of the Oslo Region *Clorinda* only occurs commonly in the storm-deposited sandstones of the Vik Formation at Skien and Porsgrunn (e.g. Localities 17,23) and also in the base of

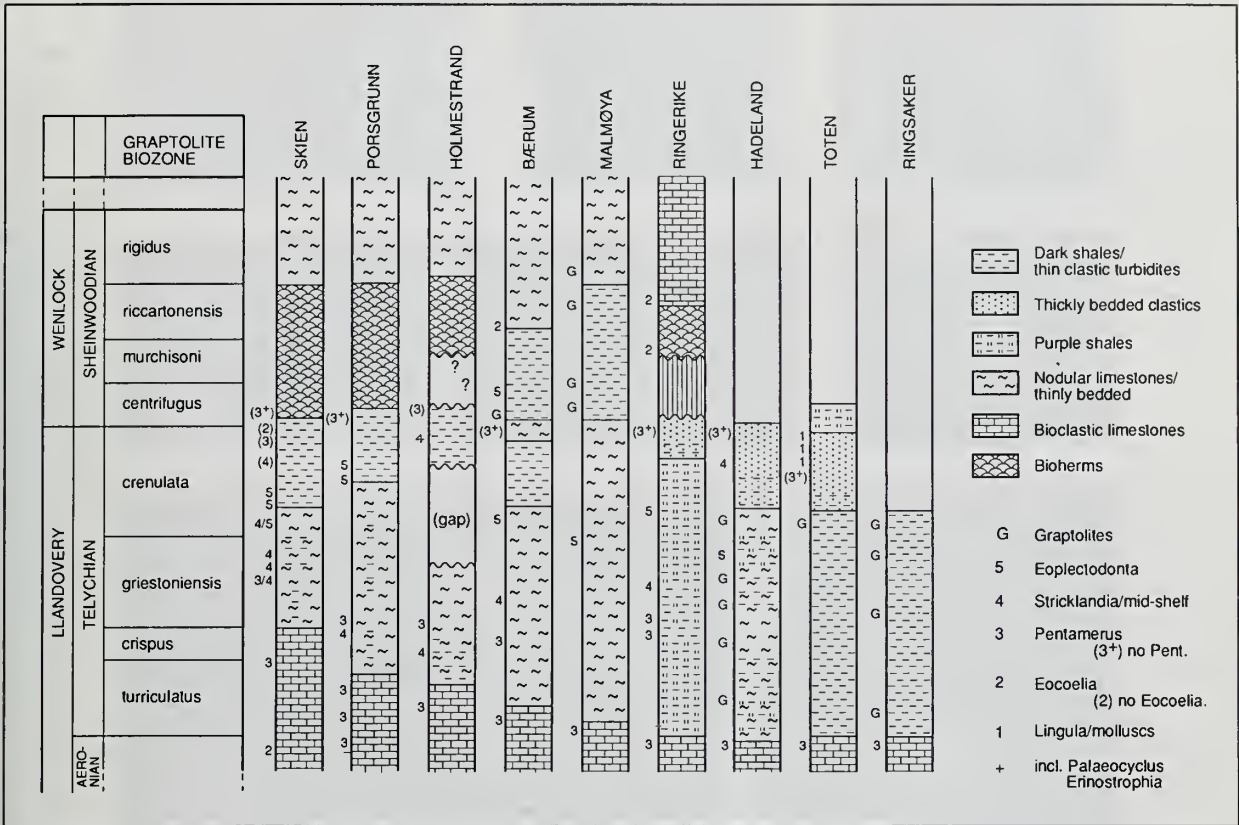


Fig. 6 The lithologies of the rocks shown in Fig. 4, together with the animal communities present.

the Vik Formation on Malmøya, and at the top of the Rytteråker Formation and at the base of the Vik Formation at Sandvika (Baarli 1990).

LATE LLANDOVERY AND EARLY WENLOCK FORMATIONS OF THE OSLO REGION

Vik Formation

This formation has its type area in the Ringerike district, where it has been divided into the Storøysundet, Garntangen and Abborvika Members (Worsley *et al.* 1983, p. 22) and where it is 80 m thick, as opposed to 55–70 m in the Oslo–Asker area. It overlies the Rytteråker Formation, which consists chiefly of bioclastic limestones (Möller 1987,1989). Although there are no continuous sections through the Vik Formation in the south of the Oslo Region, we estimate that the true thickness in the Skien and Porsgrunn districts is approximately 60–70 m. There is great lithological variation in the formation. Concretionary limestones with nodules at various sizes dominate the unit in Skien, Porsgrunn and Oslo-Asker, characteristically with maller ‘chicken-wire’ nodules. Clastic content increases further north, and the three members in the type area are hale-dominated. The Storøysundet and Abborvika members are pale to dark reddish-brown shales, separated by the

Garntangen Member’s greenish-gray shales and nodular limestones. At Holmestrand (on Killingholmen Grid Ref. NL 752995) there is only a partial section which seems to represent the middle of the Vik Formation and consists of 5.5 m of shaley limestone followed by 1.5 m of more nodular limestone (but basically packstone or grainstone) and 16 m of thinly-bedded bioclastic limestone with shaley interlaminae, above which is the sea. Below this section there is an unexposed interval which we estimate at 12 m thickness of rock, underneath which Kiaer (1908, p.206) saw 2 m of shaley limestone which he also attributed to what we would now call the Vik Formation above the Rytteråker Limestone.

The dating of the Vik Formation has been achieved solely by evolving brachiopod lineages and to a lesser degree by palynomorphs — no graptolites have yet been found in the formation, and the species of *Stricklandia*, *Costistricklandia*, *Pentamerus* and *Pentameroides* have been noted above. In general, the distribution of the various animal communities (Fig. 6) shows a deepening upwards sequence from *Pentamerus* through *Stricklandia* to *Eoplectodonta* dominated assemblages. However, in the south of the area, in Skien, Porsgrunn and Holmestrand, there is a suggestion of an initial shallowing phase from *Stricklandia* to *Pentameroides* assemblages, although the sequence is much thinner there than to the north, for example in Ringerike. The succession in the Oslo district, for example in Malmøykalven, although not abundant in depth-diagnostic brachiopods, suggests oscillation amongst the dominant limestone facies, with notable variation from low- to high-energy sediments. Baarli (1990)

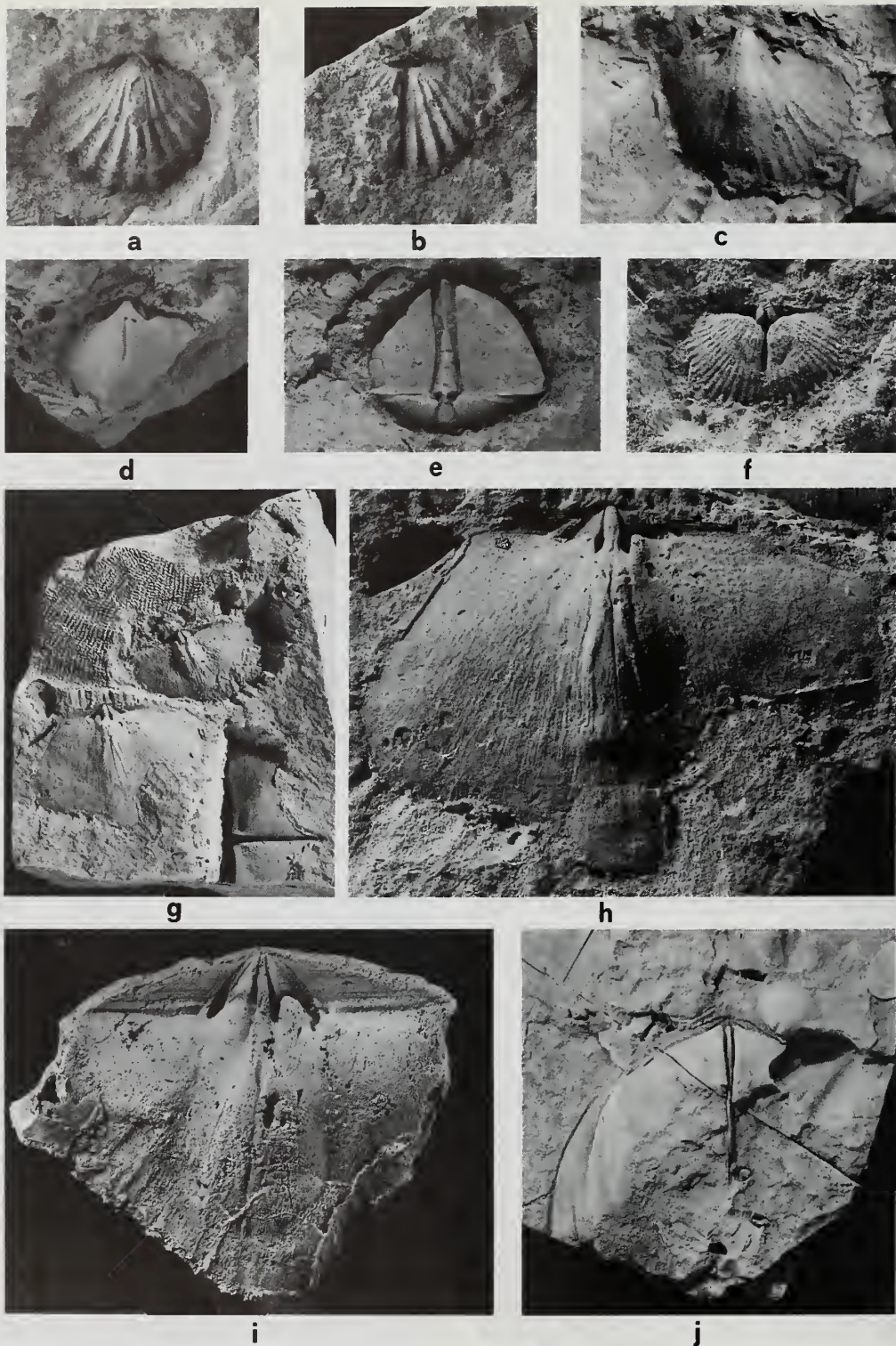


Fig. 7 Late Llandovery brachiopods from the Oslo Region. 7a–c, *Eocoelia hemisphaerica* (J de C Sowerby, 1839), internal moulds of two pedicle valves (BC 6509a, BC 6503), and a brachial valve (BC 6509b) from Rytteråker Formation, Hoppestad, Locality 11, 7a,b x 2.5; 7c x 4; 7d, *Eocoelia sulcata* (Prouty, 1923), internal mould of pedicle valve BC 6730 from Porsgrunn Formation, Holmestrand, Locality 3, x 2; 7e, *Cyrtia exporrecta* (Wahlenberg, 1818), internal mould of conjoined valves, BC 10584 from Porsgrunn Formation, Porsgrunn, Locality 22, x 2; 7f, *Skenidioides lewisii* (Davidson, 1848), internal mould of a brachial valve, BC 6290, from Vik Formation, Porsgrunn, Locality 17, x 4; 7g–i, *Stricklandia laevis* (J de C Sowerby, 1839), 7g, block BC 10716 showing internal moulds of two brachial valves and one pedicle valve, x 1; 7h, enlargement x 3 of the brachial valve in the lower left of Fig. 7g, from Vik Formation, Skien, Locality 25; 7i, internal mould of brachial valve BC 10505 from Vik Formation, Ringerike, Locality 34, x 3; 7j, *Pentameroides subrectus* (Hall & Clarke, 1893), internal mould of brachial valve, BC 6915, from Vik Formation, Porsgrunn, Locality 17, x 1.

has recorded a *Stricklandia* assemblage 18 m above the base of the Vik Formation at Malmøya above deeper water *Clorinda* assemblages in the lower 10 m, and below a probably deeper assemblage at 32 m. She also noted various ecological and sedimentological features in that section which indicate soft or even soupy substrates.

Ek Formation

The Ek Formation is confined to the north of the Oslo Region and is exposed in the Toten, Hamar and Ringsaker districts, where it consists of graptolitic shales without shelly fossils. There are no continuous sections, but the formation appears to be less than 100 m thick in Toten, Hamar and Ringsaker; Kiaer (1908) estimated approximately 95 m. In the Hadeland area, beds are present which are intermediate in lithological characters between the Ek and the Vik formations, for example in a railway cutting (Grid Ref. NM 787822 to 787825) and nearby series of temporarily exposed roadcuts near Jevnaker (e.g. at NM 781828) we have measured 98 m below the Bruflat Formation consisting of alternating reddish and grey-green shales and mudstones with occasional horizons with small nodules some of which include deeper-water shelly fossils such as *Clorinda*, *Eoplectodonta* and *Dicoelosia*. Below this section there is a gap representing an estimated 45 m of rock overlying 15 m of exposed Rytteråker Formation.

The dating of the Ek Formation has been achieved entirely by graptolites. Howe (1982, p. 23) has recorded the *turriculatus*, *crispus*, *griestoniensis* and *crenulata* zones from the formation. Apart from the deep water indicated both by the sediments and also by the absence of shelly faunas in Toten and Brummundal, there are no clear indications of depth fluctuations in the north of the region; however, in Hadeland some relative shallowing near the top of the sequence is indicated by the incursion of *Clorinda*, *Eoplectodonta* and *Dicoelosia* mentioned above.

Bruflat Formation

Although the original type section of this formation is near Bruflat in the Toten district (Strand & Størmer 1955, Skjeseth 1963), the section along the railway line near there (Grid Ref. NN 876238) shows only approximately 22 m of the formation, with neither a top nor a base visible and much faulting present. The best sections are in the Ringerike area, where D. Alm (pers. comm. 1985) has measured 120 m thickness; in the Hadeland area, where we have measured 182 m in a railway cutting 3 km north of Jevnaker (Grid Ref. NM 787822 to 787825) and in the Reinsvoll railway cutting, Toten (NN 881269), where we have measured 111 m of a section which we estimate to be 190 m thick in total. Although this is still one of the thickest formations present in the Silurian of the Oslo Region, our current measurements and estimates are much thinner than those previously published (e.g. the 400–500 m of Worsley *et al.* 1983, p. 27). The lithologies consist of greyish-green silty shales with individual units up to 1 m thick interbedded with thin to thick calcareous siltstones and sandstones in a coarsening-upwards sequence, with shell-lags of bioclastic limestones rich in shelly fossils near the top. In a single apparently unfossiliferous section near Reinsvoll, Toten (Grid Ref. NN 876270), we have measured 10 m of reddened beds in a faulted section which may be assigned to the Reinsvoll Formation (Worsley *et al.*

1983, p. 30), but the biostratigraphical significance of that formation is obscure.

The age of the Bruflat Formation is known from the *Costistricklandia lirata* found 30 m below the top of the formation in Ringerike and from the microfossils noted earlier. Dating in the Hadeland and Toten areas depends on the lower *crenulata* Zone graptolites in the underlying Ek Formation and in the *Erinostrophia*–*Palaeocyclus* assemblages found near the top of the formation (Fig. 8b–e) which indicate that the whole formation there, thick though it is, was laid down within *crenulata* Zone time. The Bruflat is a shallowing upward sequence, from the deeper-water Ek shales at its base to the near-shore molluscan dominated assemblages at the top of the formation.

Skinnerbukta Formation

This formation, which is 80 m thick in its type area at Skinnerbukta (Grid Ref. NM 894381) on Malmøya in the east of the Oslo district, overlies the Vik Formation in the Oslo and Asker districts. Apart from at Skinnerbukta itself, the Skinnerbukta Formation is poorly exposed and hence poorly documented, but we were fortunate in that there was a temporary exposure in 1986 through almost all of the formation near Øverland, Baerum (Grid Ref. NM 871444), where we were able to measure 91 m of shales and mudstones up to a 1 m transitional junction with the base of the overlying Malmøya Formation. Worsley *et al.* (1983, p. 30–31) also assigned Kiaer's 8a and 8b subdivisions to the Skinnerbukta Formation in the Skien, Porsgrunn and Holmestrand areas, but we now assign these beds to the new Porsgrunn Formation.

The age of the Skinnerbukta Formation is known from the graptolites recovered by Howe (1982) at Skinnerbukta itself and from the new finds reported above from the Baerum area, which together represent the *centrifugus*, *murchisoni* and *riccartonensis* zones of the early Sheinwoodian. There is an almost complete lack of shells near the base of the formation, but rather more shelly faunas occur progressively higher up; since the Skinnerbukta consists largely of turbidites, lateral displacement of these shells may have been considerable and so although a shallowing-upwards sequence is suggested, this cannot be proved. Thus the newly revised Skinnerbukta Formation can be considered to be entirely of Wenlock age (Fig. 5), and not reaching down into the Llandovery in places, as previously thought (Worsley *et al.* 1983).

Porsgrunn Formation

Above the Vik Formation and below the early Wenlock reefs of the Braksya Formation there are a variety of rocks, which are well exposed in the north of the Oslo Region (the Bruflat Formation of Toten, Hadeland and Ringerike) but poorly exposed from the Oslo–Asker districts southwards. These latter rocks have been grouped hitherto within the Skinnerbukta Formation (Worsley *et al.* 1983, p. 30), but in the present study it has become apparent that they are better divided into two separate formations: (a) the true Skinnerbukta Formation of Malmøya and Baerum, which are thin-bedded dark shales and calcareous turbidites now known to be of Wenlock age; (b) a new Porsgrunn Formation, which consists of a variety of deeper shelf, largely bioturbated chiefly mudstones, but with subsidiary siltstones and occa-

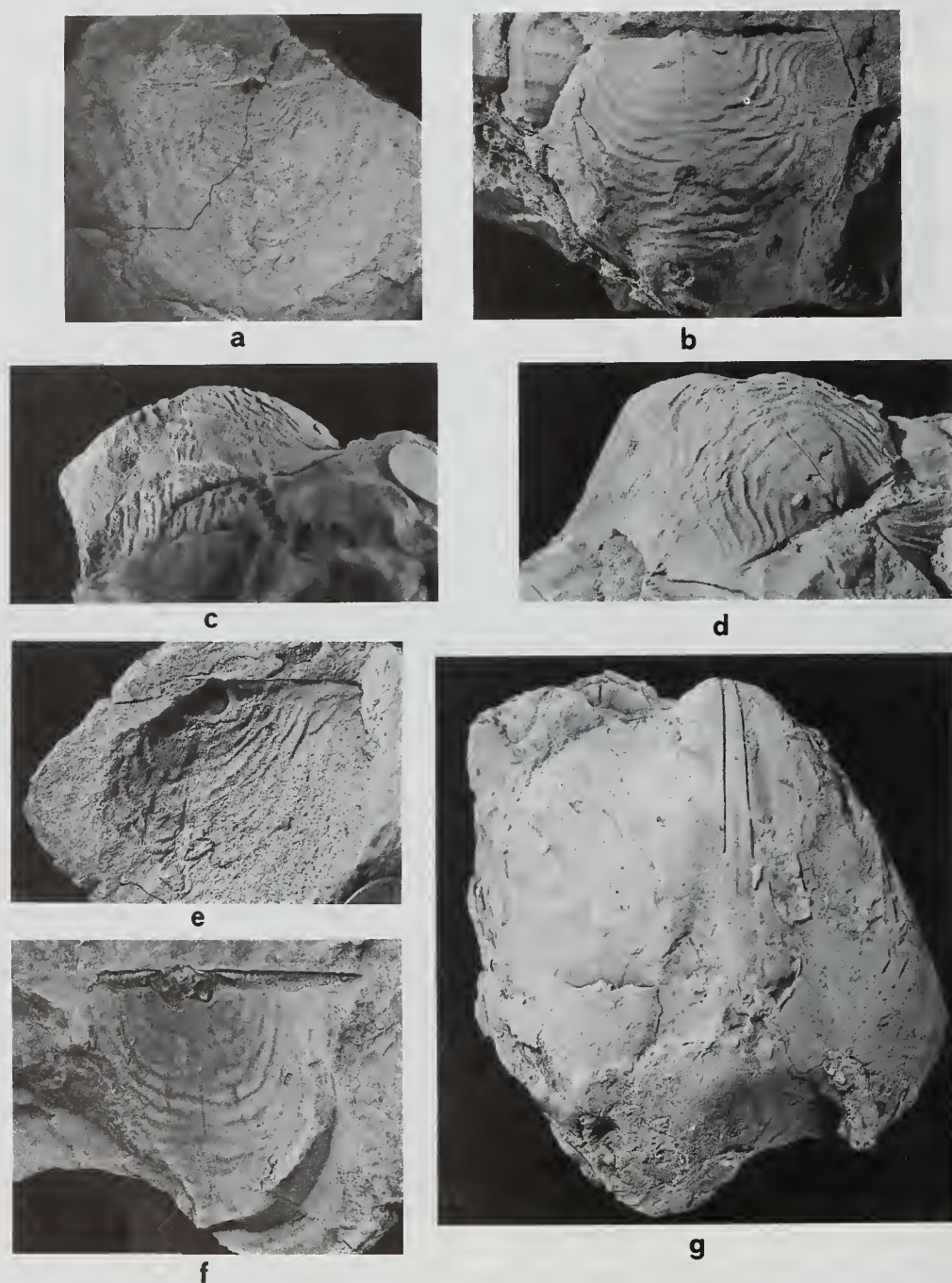


Fig. 8 Late Llandovery brachiopods from Ireland and the Oslo Region. 8a–f, *Erinostrophia undata* (M'Coy, 1846); 8a, internal mould of brachial valve, NMING F77475, lectotype selected Cocks (1978, p. 128), from Kilbride Sandstone, Egool, Ballaghadareen, Co. Mayo, Ireland, x 1; 8b–d, internal mould of a pedicle valve, BC 6686 from Bruflat Formation, Hadeland, Locality 14, x 1.5; 8e, internal mould of a brachial valve BC 6690 from the same locality, x 1.5; 8f, internal mould of a brachial valve from Porsgrunn Formation, Skien, Locality 4, x 1.5; 8g, *Pentamerus oblongus* J de C Sowerby, 1839, internal mould of a brachial valve, BC 10473 from Rytteråker Formation, Malmøykalven, Locality 28, x 1.5.

sional nodular limestones, which are all of late Llandovery age. The stratotype of the new formation is a series of discontinuous exposures along Øyekastveien, Porsgrunn (from Grid Ref. NL 369554 to 370555). The base is defined at NL 369554, where a 1.5 m transitional muddy limestone is seen from the underlying Vik Formation followed by massive mudstones with occasional shelly bands (e.g. Collection 22 at 5 m above the base). These are followed by siltstones and mudstones with thin carbonate horizons, much bioturbated, followed by a greater proportion of mudstones with (near the top) some thicker siltstones and larger limestone nodules developed, in which are seen numerous *Palaeocyclus* (Fig. 4). The junction with the overlying Braksøya Formation is clearly exposed, and the total thickness of the Porsgrunn Formation at its type section is estimated at 52 m.

Dating of the Porsgrunn Formation has also been achieved by the new finds of *crenulata* Zone graptolites together with *Eocoelia sulcata* in the Holmestrand district and by the association of *Erinostrophia* (Fig. 8f) and *Palaeocyclus* in the upper part of the formation in the Skien and Porsgrunn districts, indicating that the whole formation probably lies within the *crenulata* Zone. The faunal assemblages indicate a general shallowing upwards from the deeper-water *Eoplectodonta* bearing beds near the base to the *Palaeocyclus*–*Erinostrophia* horizons near the top of the formation.

Braksøya Formation

This formation was recognized by Worsley et al (1983) only in the Skien and Ringerike districts, but we have also found it overlying the Porsgrunn Formation at Kommersøya in the Holmestrand district. The formation consists chiefly of carbonate rocks and contains many bioherms. The age is determined by the occurrence of *Eocoelia sulcata* at Skien, and *E. angelini* in beds immediately overlying the formation in the type section at Braksøya, Ringerike. A faunal revision of the Braksøya has not been undertaken in the present work, although a sample tested for conodonts by H.A. Nakrem from Locality 7 proved barren.

DISCUSSION

This contribution augments and synthesises the rapidly growing body of biostratigraphical and sedimentological information which has been generated since Worsley et. al. (1983) established the present stratigraphical framework for the marine Silurian succession of the Oslo Region. The relationships depicted in Figs 5 and 6 are derived from a considerable database and the correlations are arguably as well constrained as present exposures will permit. It is therefore relevant to discuss the implications of these correlations and palaeobathymetric assignments for our understanding of the Oslo Region's development during the late Llandovery, especially taking into account recent developments elsewhere in the field of sequence stratigraphy and their applications to the genetic interpretation of rock sequences (e.g. Galloway 1989). The Oslo Region is particularly interesting in this respect as we may attempt to distinguish there between the effects of large-scale sea-level change and local tectonic imprint upon sequence development. We are naturally limited by the two-dimensional nature of Silurian exposures throughout the region, a feature not appreciably improved by

attempts at palinspastic reconstruction (Fig. 9), but we can clearly distinguish the changing groupings of different districts with time.

In general terms we can recognise one depositional megasequence which is generally coincident with the Telychian, conforming to a full cycle between two major highstands in sea-level. These highstands have been suggested by Johnson et. al. (1991) to have large-scale — possible intercontinental — distributions. The base of this megasequence essentially coincides with the junction between the underlying Rytteråker and the overlying Vik or Ek formations in central and northern districts of the region. This transition represents a rapid deepening from shallow water carbonate shoals and patch reefs to the moderately deep shelf red shales and nodular limestones of the Vik Formation in Ringerike, Baerum and Oslo or to the deep shelf to basinal graptolitic shale environments of the Ek Formation in Hadeland and further north. As tentatively suggested by Bjørlykke (1983) and elaborated by Baarli (1990) this deepening may have been related to the development of a local basin as an isostatic response to nappe emplacement in the developing Caledonides to the northwest.

On present evidence the base of the Vik Formation may be penecontemporaneous both in the Ringerike and Oslo districts; there is insufficient evidence to either support or disprove the models of Møller (1988) and Baarli (1990) which suggest significant younging southeastwards from Ringerike to Oslo. However, the base of the formation in Skien does appear to be significantly younger than in either of these districts. Although the *Pentamerus*/*Pentameroides* transition is still not precisely dated, representatives of this lineage indicate that the basal Vik Formation in Skien correlates with the deepening trend suggested by the upper parts of the middle Garntangen Member of the formation in Ringerike.

The Vik Formation in Oslo and Baerum has earlier been suggested as representing ongoing deepening through the Telychian (Johnson & Worsley 1982). Increased knowledge of conodont faunas and benthic assemblages (Nakrem 1988, Baarli 1990) refute this suggestion, and indicate somewhat oscillating conditions, with a phase of more pronounced shallowing in the *crispus* to mid- *griestoniensis* biozones. Thus, throughout the Telychian these areas lay on the northern margins of a moderate depth nodular carbonate platform immediately south of a ramp development which sloped down into the Ek shale basin. The Ringerike district occupied an intermediate position between these regimes, with shale development at times of relevant highstand and carbonates around the *crispus* to *griestoniensis* phase with shallower conditions. As yet insufficiently studied or understood are the occurrences of intraformational conglomerates and possible slump/slide phenomena in the Vik Formation of Malmøya in the Oslo district itself, which perhaps indicate tectonic instability along the northern margins of the carbonate platform.

The development of the Bruflat Formation in the latest Llandovery offers more direct and compelling evidence of tectonic controls on the evolution of the area — not least when we examine the abrupt break in lithofacies and depositional styles between the Vik and Bruflat formations in the Ringerike district. Although the Bruflat Formation in its type area is thinner than was suggested by Worsley et al. (1983), this unit still represents depositional rates an order of magnitude larger than those shown by older sequences in the Oslo Region. As a direct corollary to the earlier development of a

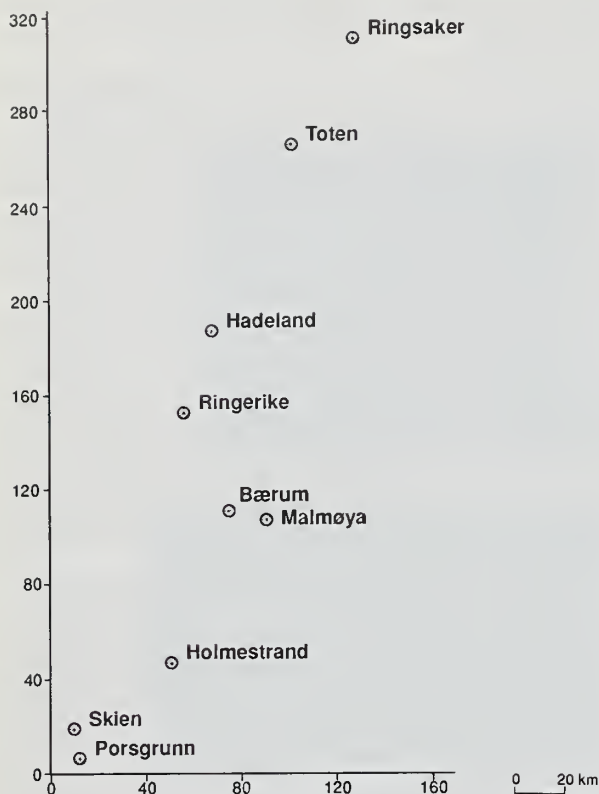


Fig. 9 Diagram showing the original relative positions of the various districts in the Oslo Region assuming a subsequent tectonic shortening of one third.

downwarped basin in the northern parts of the region, the development of the Porsgrunn Formation in southern districts suggests a deepening trend pencontemporaneous with the coarsening and shallowing-upwards sequence of the Bruflat Formation to the north. This southern deepening trend carried on through the *griestoniensis* and *crenulata* biozones before stabilisation in the latest Telychian.

Thus the picture which emerges suggests that the early Telychian highstand of the Oslo Region more probably reflected local tectonics than larger scale phenomena. Variations within the Telychian sequence itself also suggest local tectonic control, with profound variations in the northern districts and more subtle but still well-defined changes in the south. The entire depositional sequence terminated with general shallowing-upwards trends throughout the region. Both in Ringerike and in the southern districts there was an apparent depositional break before the development of the shallow-water carbonates of the Braksøya Formation; in sequence stratigraphy terms this break corresponds to a lowstand prior to the earliest Wenlock development of a maximum flooding surface marked by the clasts at the base of the formation. It is unfortunate that we have no direct evidence of the post-Telychian development in northern districts, although the red beds of the Reinsvoll Formation might represent back-lagoon lateral equivalents of the Braksøya Formation. The Telychian facies and subsidence patterns in the region were now reversed, as the sequence boundary in Oslo and Baerum suggests initially higher subsidence rates and development of a rimmed basin filled by the

graptolitic shales of the Skinnerbukta Formation, prior to shoaling into the open marine carbonates of the Malmøya Formation. Thus, although the Telychian Stage may be a good operating unit in global terms because of its definition at base and top by sequence boundaries reflecting sea-level change; variation within the time interval suggests local isostatic response to nappe emplacement north-west of the present Oslo Region. The most marked variations are those nearest to the Caledonian Front in the northern districts, with more distal response first in Skien, and then in the earliest Wenlock in the Oslo district itself.

It would be relevant to continue this study into the Wenlock so that closer restraints could be imposed upon our knowledge of the final phase of marine sedimentation in the Oslo Region. However, there are greater problems in biostratigraphic precision in the Wenlock sequences. The platform carbonate deposits which dominate that succession contain benthic faunas which, although very useful for palaeoecological analyses, lack the coeval evolutionary lineages found in the shelly faunas of the Llandovery.

ACKNOWLEDGEMENTS.

We are most grateful to Dr R.B. Rickards and Dr N.J. Morris for identifying our graptolites and molluscs respectively. We also thank D. Alm for permission to use his measured section of the Ringerike district and acknowledge critical comments by G. Baarli, M.G. Bassett and M.E. Johnson on an earlier version of the typescript.

APPENDIX 1: A NEW GENUS OF BRACHIOPOD

Order STROPHOMENIDA King 1846

Superfamily STROPHOMENACEA King, 1846

Family STROPHEODONTIDAE Caster, 1939

ERINOSTROPHIA gen. nov.

TYPE SPECIES. *Orthis undata* M'Coy, 1846.

DIAGNOSIS. Like *Protomegastrophia* Caster, 1939, but with pronounced but discontinuous rugae over the whole shell and rounded rather than blade-like cardinal process lobes. Transverse socket ridges. No dental plates.

DISCUSSION. Only one species of this distinctive genus is so far known. A review of the genera close to the *Brachypriion*-*Megastrophia* plexus was undertaken by Harper & Boucot (1978), but the striking rugae of the new genus remain distinctive from all its relatives. The erect form of the cardinal process lobes of *Erinostrophia* and *Protomegastrophia* differs from the anterior-facing cardinal process lobes of *Brachypriion leda*, the type species of *Brachypriion*. A current review of stropheodontid brachiopods for the revised *Treatise on Invertebrate Paleontology* suggests that the form and position of the cardinal process lobes are the most important criteria for familial classification in this group. In the type species of *Erinostrophia* the denticles are present for approximately half the width of the hinge line. The absence of dental plates separates the new genus from the closely related *Eomegastrophia* which occurs in the later Aeronian Pentamerus Beds of Shropshire.

***Erinostrophia undata* (M'Coy, 1846) (Figs. 8a–f)**

- 1846 *Orthis undata* McCoy, p.36, pl.3, fig.21
 non 1852 *Leptaena undata* (M'Coy); M'Coy in Sedgwick & M'Coy, p.234, pl.1H, figs 38,39
 1861 *Strophomena walmstedti* Lindström, p.372, pl.372, pl.13, fig.16
 1868 *Strophomena walmstedti* Lindström; Davidson p.18, pl.13, fig.16
 1871 *Strophomena walmstedti* Lindström; Davidson, p.290, pl.40, figs 6–8
 non 1871 *Strophomena deltoidea* Conrad var. *undata* (M'Coy); Davidson, p.295, pl.39, figs 23.24
 1974 *Megastrophia* (*Protomegastrophia*) *walmstedti* (Lindström); Bassett & Cocks, p.16, pl.3, figs 5–9
 1978 *Megastrophia* (*Protomegastrophia*) *undata* (M'Coy); Cocks p.128
 1978 *Brachyprion* (*Brachyprion*) *walmstedti* (Lindström); Harper & Boucot, p.16

TYPE SPECIMENS. Lectotype of *undata* (selected Cocks 1978, p.128) National Museum of Ireland, Dublin NMING: F7475 (previously registered NML.G.20.1976), a brachial valve, the original of M'Coy 1846 pl. 3, fig 21 from Kilbride Sandstone (Telychian), Egool, Ballaghadareen, County Mayo, Ireland refigured here (Fig. 8A). Lectotype of *walmstedti* (selected Bassett & Cocks 1974, p.16) Naturhistoriska Riksmuseet, Stockholm, Sweden RMS Br 102367, conjoined valves, the original of Lindström 1861, pl.13, fig.16, from Lower Visby Beds (Telychian), Visby, Gotland, Sweden.

DISCUSSION. This species has been described and figured from Ireland, Gotland and the Pentland Hills, Scotland (Bassett & Cocks 1974, pl.3, fig 6) and has been well-known since the mid-nineteenth century. It was listed as *Strophomena walmstedti* by Kiaer (1908) from the Oslo Region, but not described or figured by him. *Erinostrophia undata* is common in the upper part of the Bruflat and Porsgrunn formations and appears to be restricted to rocks of later Telychian age (see above), both in Norway and elsewhere in Europe.

APPENDIX 2: LIST OF LOCALITIES

1. Porsgrunn Formation, shore exposure, Kommersøya, Holmestrand, NL 750989
2. Porsgrunn Formation, shore exposure, Kommersøya, 1.5m above Locality 1
3. Porsgrunn Formation, shore exposure, Kommersøya, 1.2m above Locality 2
4. Porsgrunn Formation, roadside 100m W of Gjerpen Church, Skien, NL 347654
5. Vik Formation, outcrop behind house, Hans Hauen-sgate, Skien, NL 351638
6. Porsgrunn Formation, old quarry by sports field, Kapittel-berget, Skien NL 357629
7. Braksøya Formation, cliff at Kapittelberget, Skien, NL 357628
8. Porsgrunn Formation, side of football pitch, Skien, NL 361621
9. Porsgrunn Formation, football pitch, Skien, 20m above Locality 8
10. Porsgrunn Formation, garden outcrop, Skien, NL 372599
11. Rytteråker Formation, roadside near Tufte Farm, Skien, NL 336687
12. Saelabonn Formation, cliffs by road south of Skien, NL 369595
13. Bruflat Formation, railway cutting south of Reinsvoll, Toten, NN 881269
14. Bruflat Formation, roadside 300m N of Sogn, Hadeland, NM 785867
15. Vik Formation, shore exposure, Killingholmen, Holm-estrand, NL 752995
16. Bruflat Formation, railway cutting 3km N of Jevnaker, Hadeland, NM 787825
17. Vik Formation, factory yard, Porsgrunn, NL 364553
18. Porsgrunn Formation, cliff at Kapittelberget, Skien, NL 357629
19. Vik Formation, road by sports ground, Kapittelberget, Skien, NL 367554
20. Porsgrunn Formation, outcrop by sports ground, Pors-grunn, NL 368554
21. Vik Formation, roadside outcrop, Øyekastvegen, Pors-grunn, NL 367546
22. Porsgrunn Formation, roadside outcrop, Øyekastvegen, Porsgrunn, NL 369553
23. Vik Formation, old quarry near Kapittelberget, Skien, NL 350637
24. Vik Formation, old quarry near Kapittelberget, Skien, 1.5m below Locality 23
25. Vik Formation, roadside outcrop, Hesthagveien, Skien, NL 357625
26. Skinnerbukta Formation, temporary exposure in build-ing site 10m N of Jongsåsveien, Baerum, NM 846405
27. Skinnerbukta Formation, temporary exposure by house in Seljefløyten, Baerum, NM 827426
28. Rytteråker Formation, shore at Malmøykalven, Oslo, NM 978379
29. Vik Formation, shore at Malmøykalven, Oslo, NM 980381
30. Malmøya Formation, roadside at Daeliveien, Baerum, NM 859428
31. Skinnerbukta Formation, temporary exposure in hillside SE of Edelgranveien, near Øverland, Baerum, NM 871444
32. Vik Formation, roadside outcrop, Christians Skredvigs-vei, Baerum, NM 863428
33. Skinnerbukta Formation, temporary exposure near Øverland, 36m below Locality 31
34. Vik Formation, shore exposure, S side of Purkøya, Ringerike, NM 688568
35. Skinnerbukta Formation, roadside outcrop Asterud-veien, Baerum, NM 869442
36. Porsgrunn Formation, cliff exposure near shore, Kom-mersøya, 23.5m above Locality 3
37. Vik Formation, roadside outcrop by school gate, Skien, NL 365615
38. Steinsfjorden Formation, roadside at Øyekastvegen, Porsgrunn, NL 370555
39. Bruflat Formation, roadside outcrop, Garmtangen, Ringerike, NM 720609

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